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Analysis of Insulating Fire Bricks from Mixtures of Clays With Sawdust Addition

KEYWORDS: Kaolin, sawdust, Thermal conductivity, mechanical properties

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ABSTRACT *Production of insulating fire bricks from mixture of two different clays (kaolin and plastic clay) with sawdust addition is investigated. Suitability of kaolin with different weight percentages of plastic clay (20 to 40%) and sawdust (17 to 27%) have been added into the insulating firebricks, wet milled, spray dried, shaped and fired at different temperatures (900 – 1200°C). The properties of the resultant material then determined, water absorption, porosity, thermal conductivity, modulus of rupture, and compressive strength. The results indicate that the thermal conductivity of the samples produced from two different clays with sawdust addition decreased from 0.1429 W/mk to 0.0417 W/mk. Samples were stable at high temperatures up to 1100°C. The high porous as well as good mechanical strength produced in this study can be used for insulation fire brick in high temperature application*

1. Introduction:
The insulation fire brick is a class of brick, which consists of highly porous fireclay or kaolin. They are light weight, low thermal conductivity, and yet sufficiently resistant to temperature to be used successfully on the hot side of the furnace wall, thus permitting thin walls of thermal conductivity and low heat content. Insulation brick is characterized by the presence of large amount of porosity in it. The pores are mostly closed pores. The presence of porosity decreases the thermal conductivity of the insulating bricks.

The usage of industrial byproducts and waste materials in fired clay products as performance enhancing additives is continuously growing [1]. The ceramic sector can incorporate large amount of waste materials without relevant process modifications. The thermal treatment can immobilize hazardous components into the ceramic matrix. Due to environmental regulations, the demand of bricks with high insulation capacity is increasing, since decreasing the thermal conductivity is a decisive factor in limiting energy consumption. One way to increase the insulation capacity of the bricks is to generate porosity [2]. One of the most conventional ways to reduce thermal conductivity in ceramic materials is to modify their microstructure by incorporating lightening, pore forming additives into the clay matrix.

Different types of insulating firebricks are mainly manufactured by using the raw materials such as diatomite, perlite, expanded vermiculite, calcium silicate, fireclay, kaolin, quartz, alumina and light weight refractory aggregates by conventional method [3]. Different types of pore formers such as sawdust, foam polystyrene, fine coke, binders and organic foams or granular materials such as hollow microspheres and bubble alumina are commonly used to obtain decreased density or to produce porous bodies in the insulating material [4-6]. Insulating firebricks that have a highly porous structure (45-90% porosity) exhibit low thermal conducting values. The thermal conductivity not only depends on their total porosity, but also their pore size and shape, chemical and mineralogical composition [3].

The main objective of this work is to investigate the effect of the addition of some insulation material such as sawdust with different weight percentages with two different clays (kaolin and plastic clay) the prepared samples are to be analyzed the mechanical properties like water absorption, porosity, thermal conductivity, modulus of rupture, and compressive strength. It is important to study the contribution of the additive to the quality of the final product, especially to their mechanical and thermal insulating properties. The objective of this arrangement besides lowering the thermal conductivity is to encourage the brick factories locally and regionally to use some improved insulation materials in insulating bricks.

2. Materials and Methods:
The materials used in this work are kaolin, sawdust and plastic clay. The equipment and tools include sieve, basin, containers, iron moulds, electric furnace, kiln, measuring tape, vernier calipers, weight balance, electric oven, and Lee's disc (thermal conductivity) apparatus.

2.1 The Production of insulating fire brick:
The production of insulating fire bricks using basic raw materials kaolinitic clay and plastic clay were obtained from Govt. ceramic institute, Virudhachalam, Tamilnadu, India. The local raw materials sawdust were mixed with kaolin, plastic clay and water. Required amount of raw materials waste and enough amount of water were properly weighted and dry mix for half an hour with plastic clay. The consistency of the mixture was checked with hand filling method.

The dried material was then crushed and sieved to pass through a 150 mesh (100μm) to obtain suitable powders for pressing. Rectangular iron mould was used for hand moulding brick. The mould surface was cleaned properly and lubricated with oil. The mould was filled with a rectangular metallic punch, with row mix and again moulded. The pressed test specimen of the same composition accompanied each brick sample. The moulded bricks together with their test bricks were sun dried for 5 days. Eight batches of samples were made in which the percentages of sawdust compositions are listed in table.1.

Table: 1 composition of insulating brick samples by weight (Total weight = 1500g)

S.NO	KAOLIN (g)	PLASTIC CLAY (g)	SAWDUST(g)
1	800	300	400
2	700	400	400
3	600	500	400
4	500	600	400
5	700	400	400
6	750	400	350
7	800	400	300
8	850	400	250

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2.2 Chemical analysis:

The insulating fire bricks samples are made up of sawdust addition with different proportions (S_1 to S_8). The samples were obtained from a Government Ceramic Institute (ceramic plant), Vridhachalam, Tamilnadu, India. Upon collection, it was ground with a crushing machine. Insulating fire bricks samples were subjected to chemical analysis with the aim to obtain accurate analysis for all elements present in the sample, in such a way that some of the elements were expressed as oxides which also reveal the type of the particles. The chemical analysis of the samples was made by using X-ray fluorescence (Bruker S4-Pioneer) instrument, Pondicherry University, Pondicherry, Tamilnadu, India. The amount of sawdust added to mixtures was based on the amounts of kaolin and plastic clay of the composition.

2.3 Mechanical Properties

2.3.1 Water absorption test

Water absorption is a key factor affecting durability of brick samples. The less water infiltrates into a brick samples, the more durable is the brick samples and the better is its resistance to the natural environment. The test specimens are IFB samples in the form of bars. The dry IFB samples sintered at different temperatures (900, 1000, 1100 and 1200 °C) were weighted and then submerged in water at a temperature between 55 ˚C and 30 ˚C. After 24 hours, the specimens were taken out of water. Then, the surface water of each specimen was wiped off with damp cloths and the specimens were weighed again.

Percentage of water absorption $= \frac{W_2 - W_1}{W_1} X\ 100$

Where, w_1 – weight of the dry specimen and

w_2 – weight of the specimen after 24 hours of immersion in water.

2.3.2 Role of porosity

The density or porosity affects a number of the properties of the brick samples but probably the most important effect is its strength [7]. Highly porous insulating fire brick samples are mechanically weak. A ceramic insulating fire brick with the highest porosity has the greatest strength. The water absorption method adopted to measure the porosity values of the ceramic body is described below. The samples were heated continuously in boiling water for about six hours and left to cool over night which enables the pores to get filled up with water to saturation. The saturated specimens were then weighed by immersing in water as (W_1) and in air as (W_2). The samples were then placed in hot air oven at 200 ˚C and dried for about six hours to remove the water contents completely and then weighed as (w_3). To standardize the values of the results the percentage of porosity was calculated using the relation.

Percentage of porosity $= \frac{W_2 - W_3}{W_2 - W_1} X\ 100$

The stated procedure was repeated a number of times until consistency in the values were obtained and the average value was taken.

2.3.3 Modulus of rupture test (M.O.R)

A widely used method that measures transverse breaking strength to construction materials. The test is made on test bars the ends of which rest on knife edges while force is applied through a knife edge that is lowered midway between the ends. The breaking knife edges are moved by a dynamometer which measures the weight applied. Moduli of rupture tests were performed on a standard mechanical machine. Test specimens, measuring (93mm x 29mm x 29mm) for each IFB samples composition were dried and fired at 900, 1000, 1100 and 1200 °C. Each of them was placed one after the other on the bearing edges of the compression machine positioned 7.0 cm apart. Loads were then applied at the middle of the specimen, uniformly at 1.25 kg f per minute. The transverse breaking strength or modulus of rupture is calculate by the formula

M.O.R. $= \frac{3PL}{2bd^2} Ncm^{-2}$

Where,

L- the distance between two knife edges (cm),
b - breadth of the specimen (cm), d - depth of the specimen, and P - breaking load in kg.

3. Results and Discussion

3.1 Chemical analysis.

Eight IFB samples were the test material in this study. The results of therespective chemical analyses are tabulated in table 2. Complete chemical analysis of kaolin, plastic clay and sawdust are given in table 2 show that the amounts of major components were is agreement with the formulation. The calcium content plays an important role in clay based materials [14]. From the table 2 the sawdust (waste) contains high CaO (15.10%) value than other raw materials kaolin (5.32%) and plastic clay (0.74%) that CaO reacts at the calcite grain boundaries with Al_2O_3 and SiO_2. From clay minerals dehydroxylation to form calcium crystalline phases. The high porosity stemming from calcite particle decomposition leads to low thermal conductivity.

3.2 Water absorption.

Form the figs 1 & 2, the percentage of water absorption increased from S_1 to S_4 at 900 and 1000 °C in respect of temperature 1100°C the value in temperature 1200°C more or less equal value expect the samples S_3 and S_7. This implies that the change in the percentage of clay (Kaolin + plastic clay) together with a constant percentage of sawdust cause a decrease in the water absorption capacity of the samples (group-I). In respect of group-II samples S_5 to S_8 the increase in the percentage of clay together with a decrease in the percentage of sawdust (300g) at constant percentage of plastic clay causes a decrease in the water absorption capacity of the samples.

3.3 Porosity

Usually porosity is related to internal brick structure and geometry. We saw in this study that it can also be related to thermal conductivity that is directly correlated to mineralogy. These empty spaces or voids (though may contain air) insulate the thermal flow. Hence the reduction in thermal conductivity of the samples as the percentage sawdust admixture increases.

From the figs 3 & 4, the porosity results are shown in diagrammatically, from which it can be seen that the porosities of the samples from group-I samples (S_1 to S_4) vary from 45.26% to 56.90% with minimum at sample S_4 and maximum at sample S_3 at 1100°C. In respect to group-II samples (S_5 to S_8) vary from 40.33% to 58.55 % with minimum S_4 at 1100°C and maximum in sample S_3 at 1100°C. The same explanation is applicable to figs 3 & 4, where the porosity of the sample increase with increases the percentage sawdust admixture (group-II 20% & group-I 27%). As the percentage sawdust admixture increased it leads to increased percentage pores when the samples were fired at 1100°C [9, 10].

3.4 Thermal conductivity.

The influence of texture and porosity may be considered together because; the principal effect on the thermal conductivity is the relation between the amount of solid and of air which the heat has to transverse in passing through the material. Since air is a much better insulator than any solid material, the larger the proportion of air the greater will be the thermal insulation power of the material. Hence, a fine grained, closed-textured material has a much greater thermal conductivity than one with a coarser open texture. The relation between insulation power and texture or porosity cannot, however be expressed in very simple terms. The thermal conductivity of IFB samples will, in fact, not only depend on the total void space but also the size and the nature of the voids i.e., to whether the voids are closed or interlinked.

The high porosity IFB having low thermal conductivity and high thermal insulation properties suitable for minimizing heat losses and maximizing heat conservation in furnaces [12]. From the figure 5 & 6 thermal conductivity value starts and high level in sample S_4 at 900°C in group-I in respect of group-II (S_5 to S_8) samples, sample S_5 at 1200°C (0.1098 $Wm^{-1}K^{-1}$) and the value minimum in sample S_3 (0.0417 $Wm^{-1}K^{-1}$) at 1100°C (group-I), in respect of group-II the sample S_7 (0.0494 $Wm^{-1}K^{-1}$) at 1100°C. They derive their low thermal conductivity from their pores, while their heat capacity is determined. The insulating effect is principally the result of achieving a series of air spaces between an alternate series of solid boundaries. The more pore present and the less solid; the lower will be the conductivity. Such correlations between porosity and conductivity to be expected, which burns out during firing and leaves plenty pores in a brick induces low thermal conductivity of that brick.

3.5 Modulus of Rupture

Firing method affects strength because it determines degree of sintering, various methods of testing strength are employed commercial ceramic brick practice for special purpose, but they all require some apparatus. Modulus of rupture values are shown in figs 7 & 8 (group I & group II). From fig 7 (group I), it is also observed that the modulus of rupture of samples reduced with reduced percentage of clay content and constant percentage sawdust admixture (sawdust constant 27 %) [14]. In respect of group II samples (S_5 to S_8) the MOR of the samples reduced with increased percentage sawdust admixture (20% from 15%) with constant percentage of plastic clay. This is because as explained above, the increased percentage sawdust admixture leads to reduce matter content of the sample; less matter are available to bear the applied load. A brick of high porosity will have lower load bearing capacity than one of the same material with lower porosity.

3.6 Compressive strength

The compressive strength of IFB samples sintered at various temperatures and the function for different sawdust additions one shown in figs 9 & 10 (group I & group II). The compressive strength decreases with increase sawdust addition (group II), because higher porosity and water absorption for sawdust addition were 27% by weight with kaolin 46% and plastic clay 27% (group II) show highest maximum compressive strength an 994.33 Kg f. In respect of group-II samples the sawdust addition were 20% by weight with kaolin 53% and plastic clay 27% show highest maximum of compressive strength is 1665.54 Kg f. This could be attributed to increase in the amount of open porosity in the sample which acts as 'notch' which is a stress (both mechanical and thermal) concentrator. Also highly porous usually materials have been noted show little stability due to their high porosity [15, 16]

Conclusion:

From the discussion so far it can be concluded that, the local raw materials – kaolin, sawdust and plastic clay are suitable for the production of insulating fire bricks. The samples S_3 & S_7 are good insulating fire bricks at 1100°C [from the eight batch samples]. These are acceptable standard for hot face insulating fire bricks production. Porosity of the samples considered varies inversely as the thermal conductivity, of the samples. The porosity of the sample could be controlled by varying the percentage sawdust mixture. However, its composition can be varied to improve on its refractoriness. From the sawdust with 30% kaolin clay (S_3) (group-I and 53% (kaolin clay) S_7 in group-II) are a good insulating materials. For structural insulating fired brick where compressive strength is also important, the percentage of sawdust admixture should not exceed 20 percent (S_3 & S_7).

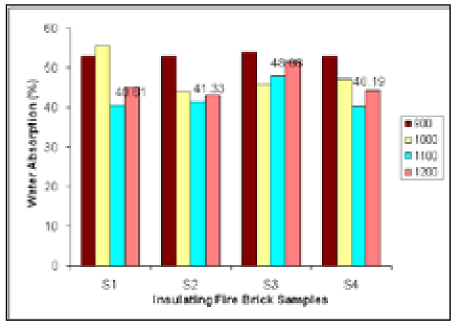

Fig. 1 Water absorption of IFB group I samples sintered at various temperatures

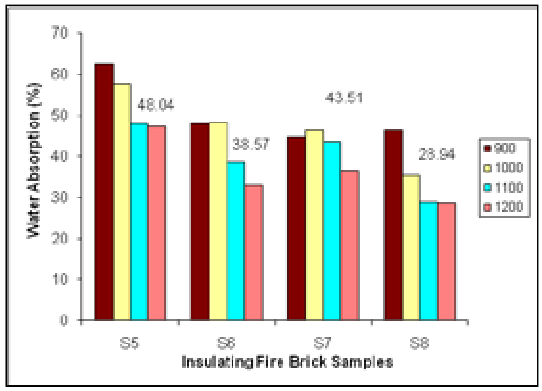

Fig. 2 Water absorption of IFB group II samples Sintered at various temperatures

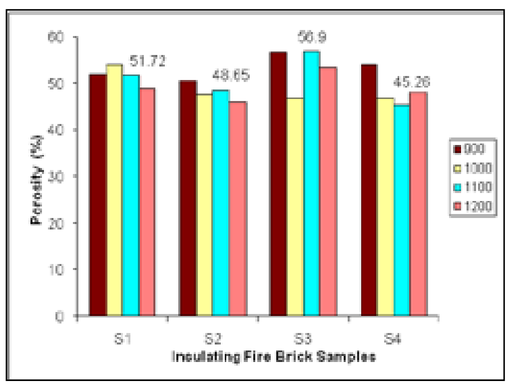

Fig. 3 Porosity of IFB group I samples Sintered at various temperatures

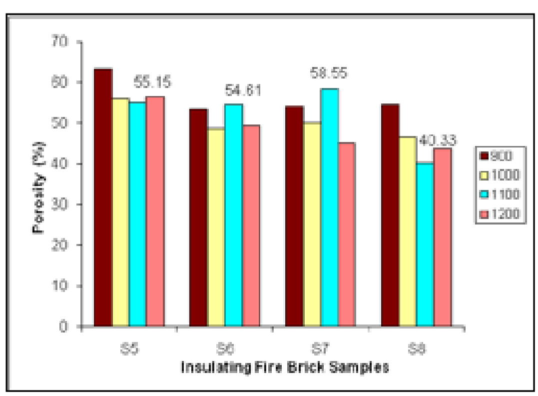

Fig. 4 Porosity of IFB group II samples Sintered at various temperatures

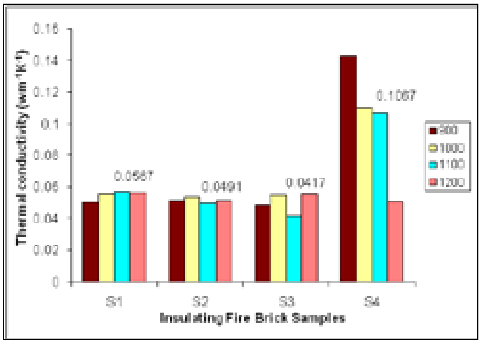

Fig. 5 Thermal conductivity of IFB group I samples Sintered at various temperatures

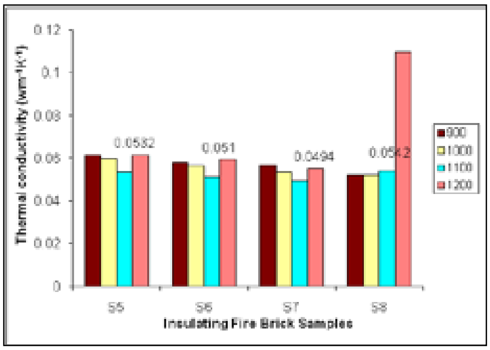

Fig. 6 Thermal conductivity of IFB group II samples Sintered at various temperatures

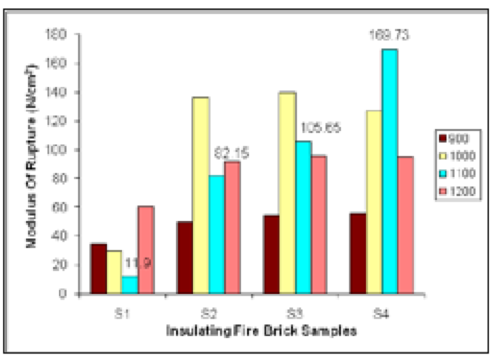

Fig. 7 Modulus of Rupture of IFB group I samples Sintered at various temperatures

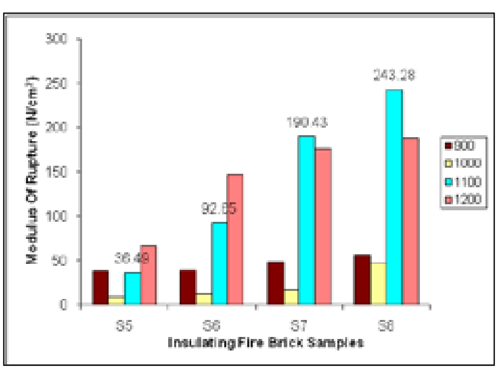

Fig. 8 Modulus of Rupture of IFB group II samples Sintered at various temperatures

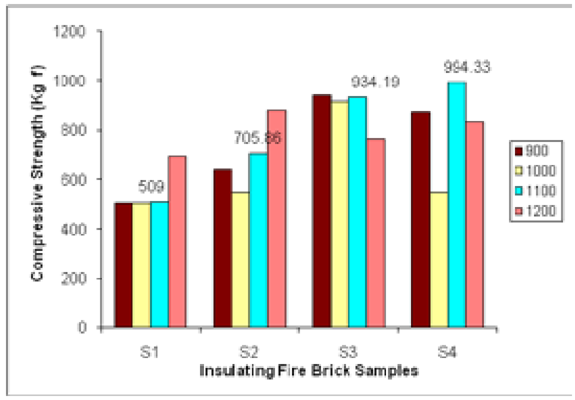

Fig. 9 Compressive Strength of IFB group I samples Sintered at various temperatures

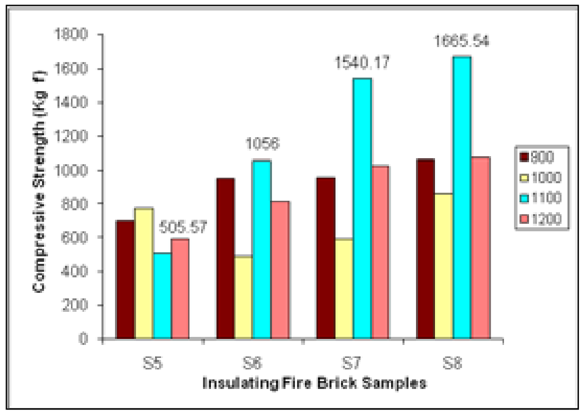

Fig. 10 Compressive Strength of IFB group II samples Sintered at various temperatures

Table 2. Chemical compositions of the raw materials [Kaolin, Plastic clay and Saw dust].

Element composition	Kaolin Concentration (%)	Plastic clay Concentration (%)	Saw dust Concentration (%)
SiO_2	62.150	53.780	51.24
Al_2O_3	31.790	31.830	11.80
CaO	5.324	0.742	15.10
Fe_2O_3	0.454	8.261	7.45
K_2O	-	2.03	5.58
MgO	0.096	1.11	0.95
MnO	0.021	0.059	-
Cl	-	0.061	1.75
Na_2O	-	0.314	-
TiO_2	-	1.212	1.73
CuO	0.005	0.013	-
SrO	-	0.016	-
P_2O_5	-	0.154	1.09
Cr_2O_3	-	0.031	-
Rb_2O	-	0.008	-
SO_3	0.050	0.016	2.51
ZnO	0.005	0.024	0.77
ZrO_2	-	0.025	-
V_2O_5	-	0.033	-
NiO	-	0.017	-
BaO	0.106	-	-

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